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ABSTRACT

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Technical Report No. 65

SPECIFICATION OF TRAINING OBJECTIVES FOR COMPUTER-AIDED INSTRUCTION

June 1970

Department of Psychology
University of Southern California

DEPARTMENT OF PSYCHOLOGY

UNIVERSITY OF SOUTHERN CALIFORNIA

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SPECIFICATION OF TRAINING OBJECTIVES FOR COMPUTER-AIDED INSTRUCTION

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"Principles of learning" are not necessarily effective in teaching people to do things. This rather surprising conclusion, suspected by many but only recently set forth by Gagne (1965) and others, came from studies in which attempts were made to apply the textbook principles about distribution of practice, reinforcement, and meaningfulness to real teaching problems. The practical results were disappointing; not much learning took place. Gagne and his colleagues proposed a different set of principles, roughly as follows:

1. A desired performance can be broken down into component subtasks which are quite distinct from each other;
2. These task components are the essential mediators of the desired performance;
3. Training design then consists of arranging for near-perfect performance of the subtask components, followed by practice in performing these components in the proper sequence (Tiffin & McCormick, 1965).

This model for training design places great significance upon the identification of the component tasks, and upon assuring mastery of them. Hence the present paper, which is directed to the business of formulating objectives. After a brief discussion of the previous work done on this problem, by educators, industrial people, and the military, we turn to those requirements which are most germane to the present CAI technology. And we suggest that accomplishing an objective is basically a realization of a <u>relationship</u> by the student, with the relationships being defined by the underlying physical relationships of the system being taught.

Over the long span of years one can discern two rather different approaches to the matter of setting educational goals. One of these originates with a consideration of what skills and knowledges the ideal "educated man" should display. This "start from the top down" approach is reflected in the educational prescriptions of the classical philosophers, and it is also implicit in the liberal-arts tradition that we know today. Within this approach there have been attempts to construct "systems" of educational objectives on logical, psychological or other grounds. A widely-cited recent attempt in this direction was made by Bloom and his panel of experts (Bloom, 1956; Krathwohl, et al., 1964). They arranged general educational goals into three domains: cognitive, affective, and manipulative motor skills. Within each domain, there are performance classifications, and these may be ordered in some way or another. For example, the cognitive domain contains six classes:

1. Knowledge
2. Comprehension
3. Application
4. Analysis
5. Synthesis
6. Evaluation

These six classes are arranged so that elements from one class are likely to be included as components of the next class in the order. "Analysis," then, which appears as fourth on the list, is postulated to depend upon knowledge, comprehension, and application; evaluation would be based upon elements of all the other skills and knowledges, and so on. The originators of this system do not remain in the ivory tower, either; they furnish typical test items for measuring the performance of the objectives. Conceivably, one could assess the cognitive adequacy of a liberal-arts curriculum, or the cognitive quality of a culture, via a

large collection of such items (one writer has even suggested that college degrees and college grades be allocated on the basis of such demonstrated skills). Also, a general set of objectives might prove to be an aid to long-range planning, to diagnosis of student achievement, and to arranging of learning situations that might facilitate the desired achievement.

A second tradition in setting educational goals stems from industrial "job analysis." Here the focus is much narrower, and more attention is directed to specific work requirements -- where the Bloom taxonomy of educational objectives would not be of much use. The historical record gives some very old and interesting job descriptions in the skilled crafts, and from about 1890 onwards there has been an increasing utilization of standardized job description formats, job indexing systems, and job codes. Job analyses are now an essential part of personnel administration, especially in large organizations. Tiffin and McCormick (1965), for example, give the following uses of job analysis information:

- Personnel Recruitment
- Personnel Development
- Performance Measurement
- Wage and Salary Administration
- Labor Relations
- Work Methods
- Job Design
- Engineering Design
- Organization Planning
- Manpower Planning and Control
- Vocational Counseling

Obviously a job description oriented toward, say, a counseling goal, might be written in different language from an analysis of the same job which was being utilized for wage setting. It is likely, too, that some "jobs" shift more radically and frequently than others, so that the permanence of a given description might vary among several jobs in the same company or agency.

What defines a job, anyway? There are many determinants: the organizational goals; the prevailing practices in physical work space and

equipments; the technological support; the organizational climate, the supply of people who can perform, or learn to perform, satisfactorily, the social status accorded to the successful practitioner; the variability and costs of unsuccessful performance; and so on. When enough of these determinants converge in similar ways in a range of locations, a "job" or "position" exists, and if the job expectations are stable enough to yield a reasonable sequence of job statuses over several years, then we may recognize a "career" (Tiffin & McCormick, 1965). A good place to look, then, for training objectives might be the job analysis.

Traditional Methods of Job Analysis

The most popular industrial method is simple observation of an experienced worker on the job, perhaps supplemented by a film, work diary, or other recording device. Here is an excerpt from a published job analysis of BREAD BAKER:

Work Performed

1. Studies requirements for day and day following, and plans production in order to have bread, rolls, biscuits, and muffins freshly baked when wanted and in quantities specified.

2. Mixes (develops) dough according to recipe: weighs and sifts flour into a bowl or mixer, adds shortening, yeast or baking powder, seasoning, and water or milk of desired temperature; either starts electric motor actuating beater that mixes and beats ingredients to form dough, or kneads dough by hand; places dough in a greased mixing bowl or proofing trough and allows it to ferment (rise or proof); may place dough in a proof box to ferment.

3. Cuts and shapes dough, sprinkling flour on work bench to prevent sticking:

   (a) Flattens and distributes dough in floured pan and places it in manually operated divider which cuts the dough into sections of equal size; may cut dough to size with knife or biscuit cutter; molds all cut dough into desired shapes, by hand; may place butter, jelly, poppy seeds, or other topping on rolls.

(b) etc.

A descriptive account like this can include practical data on working conditions, hazards, and equipment employed; it can also set minimum standards for selecting applicants for training. As an example, the "official" job description from which the above excerpt was taken recommends that the verbal intelligence score should be 75 or higher, and prescribes comparable scores for form perception, finger dexterity, and clerical skill. Also recommended is a "keen sense of taste and smell to determine whether ingredients are properly seasoned and sufficiently baked." (Tiffin & McCormick, 1965, p. 62). Training objectives and training prerequisites are thus combined in the job description.

During the 1950's many technical jobs in American Military services were broken down into "activities," and various standard recording formats were tried out. Here is a typical fragment from an analysis of the Air Force jet mechanic job; the form is completed by people actually performing the work, or perhaps by supervisors, and the respondent indicates the time it takes him to do the activity once. A collation of such forms can lead to "job design" implications, if, say, certain listed tasks are seldom or never performed, if stated times are very low, or if time variances between subjects are very large. On this approach, training objectives might be those activities which displayed certain time or difficulty features (Figure 1).

Another source of job data may be a tabulation of "critical incidents." The incidents are supposed to exemplify those behaviors which are "critical" to success or failure on the job. Criticality is not identical with importance. If a task element is important but everybody performs it correctly, it would never show up as a critical incident because no history

Job Activity	Circle the amount of time you spend in performing the activity once		
	Seconds	Minutes	Hours
Disconnects de-icing lines from engine	5 15 30	1 2 3 5 10 15 20 30 45	1 2 3 or more
Removes mounting bolts on after-burner nozzle control	5 15 30	1 2 3 5 10 15 20 30 45	1 2 3 or more
Disassembles after-burner ignitor valve	5 15 30	1 2 3 5 10 15 20 30 45	1 2 3 or more

Fig. 1. Excerpt from jet mechanic job analysis form.

of failure due to malperformance of that element would be recorded. Presumably, a collection of critical incidents demonstrating job "success" and "failure" might illuminate the behaviors leading to each of these states. People could then be trained to meet these demonstrably critical requirements. The approach has been tried, with variable results, in several technical and management domains; indeed, some of the most readable job analysis material can be found in critical incident reports (Flanagan, 1954). It does not appear that a critical incident is readily translated into a training objective, though; for one thing, an observed incident may reflect a very rare combination of environmental and personal circumstances; and then many accounts of incidents are psychologically naive and attribute the event to presence (or absence) of "leadership," "good management," and other poorly specified variables.

Motion and time study methods are oriented to separating a complicated job into task elements, and to arranging these in ways that will favor greater efficiency of task completion. "Standard times" for elements can

be determined _via_ empirical filming of performance under realistic conditions, and there are many rules for putting the elements together. A stock objection to motion and time study has been the restriction to observable and repetitive jobs; recent work, however, shows that the approach is quite applicable to complex maintenance work, and that computer compilation of time data _via_ special programs is quite feasible (Rigney, _et al._, 1966).

An ingenious extension of motion-time philosophy into the training objectives domain was demonstrated by Lindahl. The industrial task was to cut tungsten rods with a foot-operated abrasive wheel, and efficiency in the task is achieved by learning a certain time-control pattern. Lindahl attached a simple graphic recorder to the foot pedal, and thus was able to document the pedal pattern being accomplished _now_ by the trainee. It was thus possible to compare the trainee's present pattern with the record displayed by a better, more experienced operator. For Lindahl's situation a training objective would be to produce a pedal pattern sufficiently similar to an ideal one (Lindahl, 1945).

Activity analysis or task analysis, usually embraces the notion of _sequence_ or order: some tasks must be done first. Also, there will be a hierarchy, with several levels of task detail. In the illustration below, the "Replace Starter" level includes all the "little" listed tasks under it.

1. Replace the starter
   - (a) Disconnect the electrical connectors by cutting and removing the safety wire, unscrewing the nut, and withdrawing the plug
   - (b) Disconnect the starter pressure-sensing line from the starter by cutting and removing the safety wire and unscrewing the nut
   - (c) Unscrew the clamp, remove the clamp, and slide clear the air supply line to the starter

(d) (Continued)

An ordered listing like this can also contain time-to-completion for successful completion of each subtask, likelihood of a "typical" worker achieving success at the task, and dependency among tasks. A well-known study by Siegel and Wolf (1961) pushed this approach to something of a _tour de force_: a simulation of pilot activities during an aircraft landing sequence was attempted by storing subtask probabilities and time distributions in a computer, and then compiling these _via_ a sampling process. Certain outputs, such as overall likelihood of success, from the simulation resembled the success probabilities occurring in the real world. Training objectives might be derived from the stored distributions, particularly for those tasks which are most "dominant" in the sequence, or those which sensitivity runs indicate as problems.

This brief review of job analysis procedures indicates that, except for certain motion-and-time applications with the "elements," there is no generally valid system for classifying tasks or for identifying the same task in different jobs. There is no universal method for deciding whether a job-descriptive element should be called a training objective. This is probably inevitable, because the richness of behavior precludes total description and also because of the level of description which a particular analysis may require. In the next section, we examine the ways that an instructional technologist approaches the issue, and how he may carry through a specialized transformation of job data into training objectives.

The Instructional Technology Approach

As we saw, traditional job analysis procedures have recognized the problem of consistent operational definition, the problem of sequence,

the problem of hierarchical task arrangement. The training manager can benefit from experience with these methods when he lists course objectives. But he will look at the tasks always from the standpoint of the teacher, rather than from the standpoint of the supervisor, the wage analyst, or the design engineer. And this implies that, for the instructional technologist, there is a rather narrow criterion for evaluating a set of course objectives. Such a set is good if it describes "... the behavior of the student at the time he leaves the course. It is prepared in enough detail so another professional instructor could turn out a student who could do the kind of things you want him to do at the proficiency levels you desire." (Mager, 1962).

A set of instructional objectives, then, is not simply a task analysis of the way that an experienced man performs the job; experienced people may perform faster or more efficiently than new graduates could, for example. The list of course objectives would not include all those things which the student already knows or those features which might be feasibly learned only on the job itself; and it might ignore some of the social and organizational factors which condition on-the-job proficiency.

How will we know a good training objective when we see one? Of all recent writers on the subject, Mager is probably the most explicit. He says that a good objective displays five characteristics:

1. An objective says something about the student. It does not describe the textbook, the instructor, or the kinds of classroom experience to which the student will be exposed.

2. An objective talks about the behavior or performance of the student ... it describes what the student will be doing to demonstrate his achievement of your instructional intent.

3. An objective is about ends rather than means. It describes a product rather than a process.

4. An objective describes the condition under which the student will be performing his terminal behavior.

5. An instructional objective also includes information about the level of performance that will be considered acceptable. (Mager 1962)

Mager notices that the five features above can refer to <u>attitudes</u> just as well as to specific acts. If you require that a radar mechanic to be persistent in his troubleshooting, "...unless this persistence objective is made explicit, it is possible that the procedure used during instruction will turn out a student who will give up after two or three attempts. (And this is just what will happen if, for instance, the instructor makes critical comments following every student attempt to come into contact with the very equipment he is expected to master). (Mager, 1962)

The language or exact format employed in detailing the objective should not matter a great deal, provided the intent is made clear. Mager recommends, though, some regular procedure such as a three-column work-sheet with the general objective on the left, the work conditions and constraints in the middle, and the criterion for successful completion detailed in the right. It may also help to provide space for difficulty or time estimates, and the like; but the main things to aim for are clarity and simplicity of expression.

Here are a few examples of training objectives, with critical comments:

		COMMENTS
<u>EXAMPLE 1</u>.	Understand how PNP transistors work.	Too vague; "understanding" transistors can occur at many levels.

EXAMPLE 2.	Operate a PBX machine.	Better than #1, but still incomplete because criteria for performance (number of wrong connections, time delays, etc.) are not prescribed.
EXAMPLE 3.	Know how to use oscilloscope for measuring frequencies of radio carrier bands. Must measure 9 out of 10 of a random sample of VHF frequencies within an error of plus or minus 1 percent. Time allowed for unknown signal: 3 mins.	Probably adequate; the term "know" in the original phrase is ambiguous, but the additional behavior specification pins it down.

Categorizing Training Objectives

Suppose you have assembled a list of objectives which appear to meet Mager's five criteria, and that these objectives seem to cover your domain of interest reasonably well. The question may then arise as to whether they should be classified in some way or other, perhaps according to the alleged psychological processes involved.

Gagne and his associates answer this question in the affirmative; the main argument is that different performance processes require different training techniques, and therefore it can be helpful to identify the principal process involved in accomplishing each objective. He proposes an eight-category system. Mager reduces the eight categories down to the following five:

1. Discrimination
2. Problem Solving
3. Recall
4. Manipulation
5. Speech

Mager (1967) gives a similar set of performance classes (sensing, discriminating, remembering, deciding, choosing, etc.); Rigney, et al., (1968) divide activities into self-programming, information-processing, self-moritoring, sensory-motor, and memory; other schemes have been proposed by Miller (1962), Altman (1960) and others.

It does appear that preferred training methods vary noticeably with the performance category involved. Let us take discrimination and recall from Mager's list of five types. Discrimination training often follows a teaching strategy of giving the student practice in detecting differences. At first, the difference between stimulus complex A and a comparison stimulus B is coarse and easy for the student to see; as he improves his performance the difference between A and B is reduced, until an acceptable level of discriminability is attained. Or he can practice judging whether a stimulus C is most like B or most like A.

Training for specific recall might well follow a quite different procedure. If we want the student to remember "what to do next," then sequence practice might be indicated, perhaps with small chunks of the string of behaviors learned in little clusters, and eventually pieced together as a long procedural chain. Or we might furnish the student recall aids, such as lists or diagrams, and gradually reduce the information in these aids as the contents of the aids are stored in the student's memory.

Our own experience indicates that the really interesting training problems occur in the category of behavior called "problem solving," "deciding," "search," or some similar term. This is especially true in those cases where the pupil has to master some complex piece of equipment. The tough task for the technician is to decide what to do.

Much evidence shows that the technician who is an ineffective "searcher" simply does not appreciate the <u>relationships</u> between his observed datum and the underlying physical system. A routine voltage check may "logically" indicate that certain sections of a radio transmitter are functionally normal, and yet a technician will make the proper check, interpret it as "normal", and then search around indefinitely in those areas he has already eliminated. The "map" of physical relationships may have been forgotten, but most likely it was never satisfactorily learned in the first place. Teaching students to learn the set of relations, and to make inferences from them, is thus the general training objective.

It follows that a CAI system for technical training should be able to handle relational information readily, should provide for coding relationships into desired and undesired sequences, and should be able to provide to the student the implications of the things he does. Training objectives of the problem-solving category are then direct products of these stored relations in the computer.

Here is a sample of objectives which might be defined in our radar repeater case:

TERMINAL BEHAVIORS	COMMENT
1. Deduce the probable malfunction within a given circuit, given the normal circuit parameters and an adequate series of test readings and values.	Specific time and other situational requirements can be added to the objectives, as experience is gained with problems in different circuits and time distributions are accumulated.
2. Observe proper set-up and safety precautions for oscilloscope model B530. Set up time 5 minutes or less; no safety violations over a series of 10 component isolation problems.	The objective says nothing about accuracy of the measurements made. Perhaps there will be some additional specifications.

3. Given standard documentation, state the current, voltage, pulse forms or other values that should be observed at every major test point in the circuit.

Again, an accuracy specification could be appended.

We conclude this section with a chart from Banathy's text (1968, p. 83) on instructional systems. Banathy starts from a concept of purpose, and this purpose leads to the training objectives that must be realized to achieve the purpose. The "learning tasks" are then derived, and compared with the existing skills in the people to be taught and so on through system design and evaluation. Feedback loops are provided throughout. Various writers have diagrammed the design process in slightly different ways, but this particular chart is very clear in showing the logical relations, and is especially clear in the way it portrays the centrality of the purpose-objectives function (Figure 2).

Generation of Training Objectives from List Structures

Clearly, specifying training objectives is a laborious, unsatisfying job. The nature of the outcome depends on the expertise and judgment of the instructional technologist as well as on the more general objectives for the training. Training objectives written for a course in basic electricity and electronics by two different, independent groups would very likely contain many differences. Once training objectives are specified, they often are intended to serve as guides for organizing

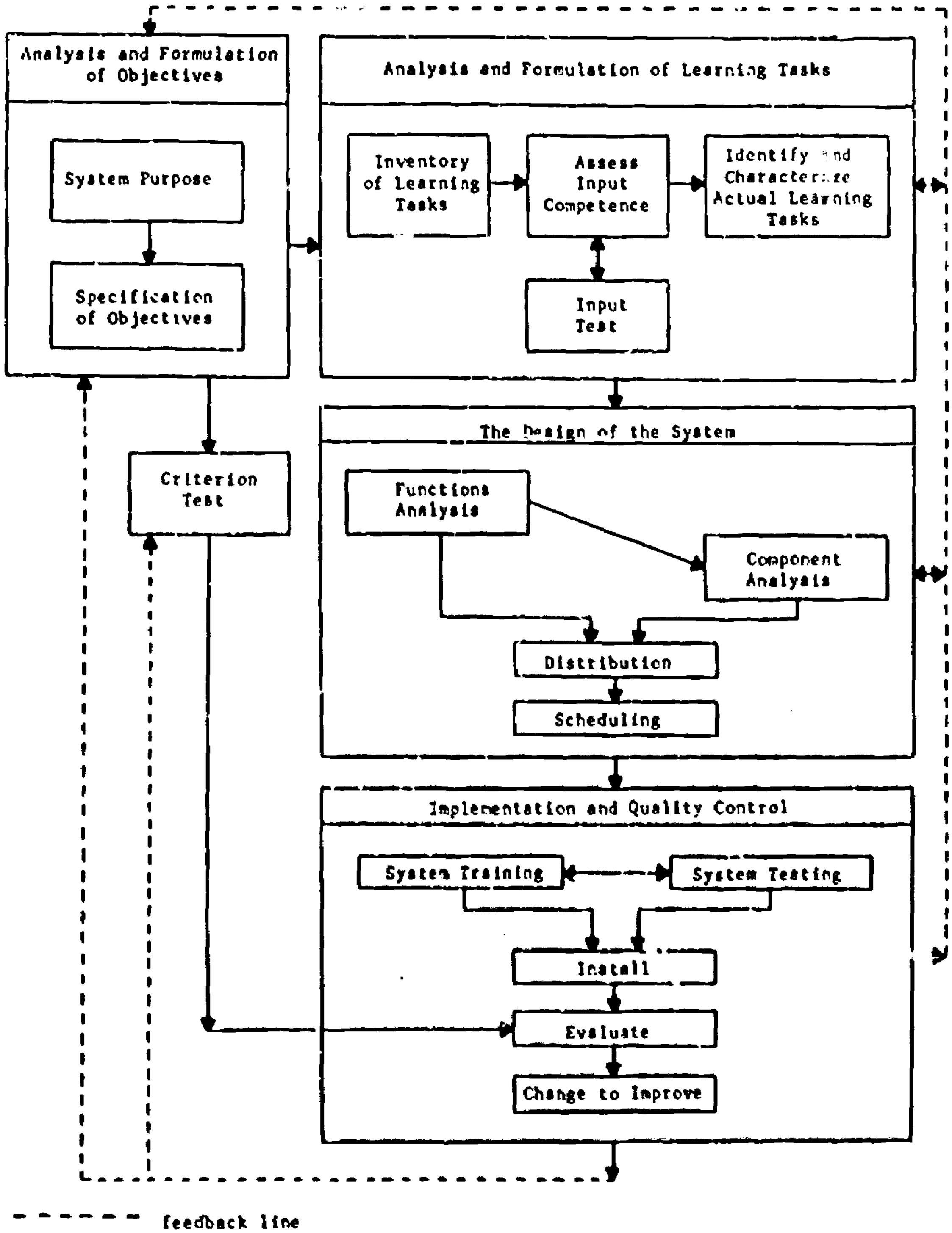

Fig. 2. The design of instructional systems.

course content, allocating instructional methods and media, and developing tests. Perhaps, though, this is too great a burden to place on a list of descriptive statements. What enabling knowledge, for example, does a student need for accomplishing a training objective? Will instructors really follow these specifications in their own teaching? There are many opportunities for loss of control over what happens between the specification of behavioral objectives and the actual results of training. Data-processing techniques offer an opportunity for better control over some of these processes. Perhaps this is as much a requirement as an opportunity: when you are writing a computer program or developing a data-base for it, vagueness must be replaced by painfully explicit detail.

At least in certain areas of training where the capability to perform tasks is the general objective, as in trouble shooting or operating equipment, the criterion tasks can be generated from data-bases describing essential features of tasks and equipment. Computer programs with appropriate logic then can generate what amounts to training objectives from these data-bases as the student is performing. This technique reduces the "slippage" between specification and implementation: the specifications are the data from which the criterion tasks are generated. The computer programs using these data can "track" the student as he performs these criterion tasks. Logic in these programs can implement various instructional tactics and various requirements for accuracy and speed of performance.

Some details of how such data-bases may be prepared may be of interest. The procedures described below were developed for programs, called TASKTEACH written in LISP. This was, and is, a powerful language to use for this

purpose because its list-processing functions and its recursiveness are beautifully suited for this type of application, in which processing lists is the bulk of the work. However, there are many different ways to accomplish the same ends with computer programming. Other programming languages could be used, and data-bases with entirely different structures could be devised, which would do essentially the same thing.

General

All input data to TASKTEACH is in the form of lists. A list is represented by a left parenthesis, followed by one or more elements, followed by a right parenthesis.

The following are lists:

```
(A   B   C)
(X   Apple   12   BC   B)
(G)
```

Elements in lists may be single or multiple characters. They may also be multiple words if they are placed in quotes. Elements may also be other lists.

The following is a list:

```
(B   "Hot and cold"   7   (A   B   C)   9)
```

The maximum length of a list element is approximately 60 characters. There is no limit to the length of a list.

The nesting of one list as an element in another may be continued to any level. The following list consists of two other lists, the second of which consists of three other lists:

$$\overbrace{(\ \overbrace{(A\quad B\quad C)}^{1}\overbrace{(\overbrace{(X\quad Y)}^{1}\overbrace{(1\quad 2\quad 3)}^{2}\overbrace{(B\quad D)}^{3})}^{2})}$$

Input for Front Panel Drill

Input for a front panel drill is prepared as follows:

1. Itemize each front panel control, switch, indicator, etc. to be identified by the student. Use the name which you wish the student to learn.

Example:

Power Switch
D.C. Meter
Fuse Light

2. Assign a code to each front panel element. Attach this symbol to the drawing, mock-up, or functioning equipment which the student will use.

3. Classify each front panel element as follows:

   C - The element is a continuous control or indicator with an infinite number of positions

   D - The element has a finite number of discrete positions

   CD - The element is continuous in one range but also has at least one discrete position

The list might now appear:

Name	Code	Type
Power Switch	P	D
D.C. Meter	DCM	C
Fuse Light	Fl	D
.	.	.
.	.	.
.	.	.

4. If desired, categorize the elements into any types of groups which will be helpful to the student. The list might now appear:

Group	Name	Code	Type
Output Indicators			
	Watt Meter	WATT	C
	Plate Current Meter	IP	C
Frequency Controls			
	Band Switch	BAND	D
	Frequency Selector	FREQ	C
	Add-Band Switch	ADD	D
	Frequency Vernier	FVERN	C

5. For each group, make a list in which the first element is the group name. Following the name, place the name of the first front panel element, its code, and its type. Repeat this sequence for all elements in the group. The first group would then appear:

```
("Output Indicators"  "Watt Meter"  Watt C
                      "Plate Current Meter"  IP  C)
```

6. Form one list out of the group lists as follows:

```
( ("Output Indicators"  "Watt Meter"  Watt C
                        "Plate Current Meter"  IP  C)

  ("Frequency Controls"  "Band Switch"  Band D
                         "Frequency Selector"  FREQ C)
                                   .
                                   .
                                   .                    )
```

There are no restrictions on spacing or placing a particular number of list elements per line. The only restriction on forming the list is that a multi-word element cannot be split up.

Example:

```
Correct      (  A   B   "Salt and pepper"
                D   E)

Incorrect    (  A   B   "Salt and
                pepper"  D   E)
```

Input for Serial Action Tasks

Input for a serial action task is prepared as follows:

1. Break the task into subtasks

   Example - Task - Replace flat tire
   Subtasks - Remove flat tire
   Place spare tire

2. Choose the task constraint which describes how the subtasks are to be performed to accomplish the task. Three task constraints have been defined. They are:

   SEQ - The subtasks must be performed in a fixed sequence

   ANY - The task will be accomplished by performing any one of the subtasks

   ALL - All the subtasks must be performed (in any sequence) to accomplish the task

3. Form a list (TN C ST_1 ST_2 ... ST_n)

   where TN is the task name
   C is the constraint (SEQ, ANY, or ALL)
   ST_1, ST_2, etc. are the subtasks

   Example:

   ("Replace Flat Tire" SEQ "Remove Flat Tire" "Place Spare Tire")

4. Repeat Steps 1 - 3 for each subtask until the subtasks become sufficiently elementary that no further detail is deemed necessary.

   Example: Taking the example one level deeper

```
("Replace Flat Tire"  SEQ
          ("Remove Flat Tire"  SEQ
              "Get Out Tools"
              "Jack Up Car"
              "Remove Flat Tire")
          ("Place Spare Tire"  SEQ
              "Place Spare on Hub"
              "Place Hub Cap"
              "Lower Jack"
              "Replace Tools"))
```

Any of the elements may be further decomposed to increase the detail which the student will receive. The elements which are not decomposed into other subtasks are called "ACTIONS." For the task shown above, an instructor may decide that "Get Out Tools", "Remove Hub Cap", and "Place Hub Cap" require no further explanation. He may break down the other elements further in any way he feels is reasonable. If he wished to describe how to "Remove Hub Cap" he would list the actions required underneath (or following) "Remove Hub Cap". In general, the sublist inside a parenthesis consist of (task name, sequence constraint, action names). This sublist may be part of a larger sublist, which may, in turn, be part of an even larger sublist. In the example above, "Remove Flat Tire" and "Place Spare Tire" are two sublists which are included in, and in this example, compose, the top level list, "Replace Flat Tire." It happens that all these tasks must be accomplished in one, fixed sequence (SEQ). The lists describing other tasks might have ANY or ALL in the positions where SEQ is in the above example.

Observe that the relationship of sublists to the higher level lists is preserved by the parentheses. In the above example, the two sublists inside a top level list are indicated by:

(( ) ( )).

When describing the task structure for operating equipment, it generally is sufficient to analyze the tasks to the level of actions performed on front panel controls, e.g., "Turn Power Switch On." In a few cases, where operation of the control is complicated, unusual, or dangerous, the analysis might go down one more level to describe explicitly the actions required to operate that one control, e.g., "Turn knob X clockwise SLOWLY until meter Y indicator just reaches 100."

Input for Troubleshooting an Electronic Circuit

1. The relationships among selected test points and selected failure modes of selected components in the circuit must be analyzed and tabulated in some form; a matrix format is convenient.

2. A list-structure may then be prepared which is analogous to that for a serial-task, described above. This will be a string of sub-lists at several levels, with level defined by parentheses. Since the computer program does not "know" what device is being described in the list, it can only look at sequence of elements in the list. Thus, the list-structure must be exact. In the following structure, each row after the first contains the data for a particular test point:

```
((Malfunction-1 Malfunction -2..................)
 (Normal Reading (Malfunction High-Reading Malfunction High-Reading)
                 (Malfunction Low-Reading))
 (Normal Reading (__________________) (__________________))
 (Normal Reading (__________________) (__________________))
        .                 .                    .
        .                 .                    .
        .                 .                    .
 (               (                  ) (                  )) )
```

Values for readings at test points may be numbers describing AC and DC voltages or resistances, or they may be more qualitative information such as waveforms, so long as the logic in the program is appropriate. Displaying waveforms to the student, of course, requires devices such as CRT terminals or slide projectors. In the latter case, slides of waveforms are stored outside of computer memory.

The information about "symptoms" to be presented to the student, which is usually at least partly verbal, may be assembled by a special input-output routine from several different places in a data base. This allows these lists to be replaced by simpler representations, such as integers, for internal processing. This can speed up the processing

and reduce CPU time costs. This is, in fact, the approach used in the latest revision of TASKTEACH, written in BASIC. In this version, the distinction between data structures for performing serial tasks and data structures for performing troubleshooting is less sharp than in the list structures described above. The front panel control manipulations necessary to develop front panel symptom information, as well as that information, can be generated from a very compact data-base, considering the complexity of the equipment involved. These developments will be described in a forthcoming technical report.

The point here is that criterion behaviors to be taught to a student can be generated from these kinds of input lists by the appropriate logic in computer programs, which can track the student, comparing his actual behavior directly with the desired behaviors. In the past, these have been frozen in long lists of verbal descriptions that are only the first step in a series of subjective judgments and transformations full of opportunities for loss of control over the training processes.

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